Instream Indexing of Coho Salmon *(Oncorhynchus kisutch)* Escapement in French Creek, British Columbia

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INSTREAM INDEXING OF COHO SALMON (*Oncorhynchus kisutch*) ESCAPEMENT IN FRENCH CREEK, BRITISH COLUMBIA

by

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ABSTRACT

Johnston, N. T., J. R. Irvine, and C. J. Perrin. 1987. Instream indexing of coho salmon (Oncorhynchus kisutch) escapement in French Creek, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1573: 37 p.

We evaluated the utility of instream indexing for estimating coho escapements in a small river system for which there were independent estimates of escapement from fence counts and mark-recapture surveys. We compared three survey designs (simple random sampling, spawning ground sampling, and "index area" sampling), three sampling unit sizes (100, 200, and 400 m), and four methods of estimation (peak live counts, peak live plus accumulated dead counts, total dead counts, and area-under-the-curve), using visual count data obtained by foot surveys. We also compared the counting efficiencies of different observers, and examined the relation between visual estimates of coho density and densities obtained by electrofishing.

Visual, foot survey estimates of adult coho densities in small headwater streams averaged 69 (± 15)% of actual densities. Actual densities were best predicted by visually estimated densities, with physical habitat variables (stream width, water depth, current speed, substrate coarseness, substrate heterogeneity, visibility) having no significant effect over the ranges at which foot surveys were possible. Observed densities of coho were not simply related to the physical habitat features recorded by us. Counts of adult coho did not differ significantly among different observers.

Indices of adult coho abundance derived from visual count data generally increased in precision with increasing sampling unit size. In general, the indices obtained from spawning ground and index area surveys were more precise than those obtained from random sampling. Coefficients of variation were about 100% for all methods. However, both the magnitude and the precision of indices of abundance varied among survey designs and methods of calculation.

Total escapements estimated from the random surveys varied between 41 and 99% of the minimum known escapement (fence count), but were only 20-48% of the probable escapement (Bayesian mark-recapture estimate). The peak live plus accumulated dead count and area-under-the-curve estimates were most accurate. Spawning ground and index area surveys in headwater areas known to be spawning areas gave similar estimates for the same methods of calculation, but accounted for only a small proportion of the probable escapement.

Instream escapement indexing assumes a known or fixed relationship between indices and escapements. There are insufficient data at present to be confident of the validity of this assumption.

RESUME

Johnston, N. T., J. R. Irvine, and C. J. Perrin. 1987. Instream indexing of coho salmon (Oncorhynchus kisutch) escapement in French Creek, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1573: 37 p.

Les auteurs ont évalué l'utilité de l'indexation en milieu fluvial en matière d'estimation de l'échappée du saumon coho dans un petit milieu fluvial pour lequel on dispose d'estimations indépendantes de l'échappeé tirées de dénombrements aux barrières et de levés par marquage et recapture. Les auteurs ont comparé trois plans de levés (échantillonnage aléatoire simple, échantillonnage des frayères et échantillonnage d'une zone repère), trois unités d'échantillonnage (100, 200 et 400 m), et quatre méthodes d'estimation (nombre maximal de saumons vivants, nombre maximal de saumons vivants plus nombre cumulatif de saumons morts, nombre total de saumons morts et surface sous la courbe) à partir des données recueillies au cours de dénombrements visuels effectués par des observateurs à pied. Ils ont aussi comparé l'efficacité de dénombrements de divers observateurs et examiné la relation entre les estimations visuelles de la densité des cohos et les densités obtenues par pêche électrique.

Selon les estimations visuelles obtenues par levés à pied, la densité des coho adultes dans les petits cours d'eau d'amont s'élève en moyenne à 69 % (± 15 %) de la densité réelle. La densité visuelle estimative fournit une meilleure prévision de la densité réelle; les variables physiques de l'habitat (largeur du cours d'eau, profondeur de l'eau, vitesse du courant, nature grossière et hétérogénéité du substrat, visibilité) n'ont eu aucune incidence significative pour ce qui est des aires de répartition qui ont fait l'objet d'un levé visuel. Les densités observées n'étaient pas uniquement liées aux caractéristiques physiques de l'habitat enregistrées. Il n'y avait pas de différence significative entre le nombre de cohos adulte noté par chaque observateur.

La précision des indices d'abondance de cohos adultes obtenus des dénombrements visuels a généralement augmenté en fonction d'une augmentation de l'unité d'échantillonnage. En général, les indices obtenus de levés des frayères et d'une zone repère étaient plus précis que ceux tirés de résultats d'échantillonagge aléatoire. Toutes les méthodes ont donné des coefficients de variation s'élevant à 100 %. Toutefois, la valeur et la précision des indices d'abondance ont varié selon le plan d'échantillonnage et les méthodes de calcul.

L'échappée totale estimative obtenue des résultats de levés aléatoires a varié de 41 à 99 % de l'échappée minimale connue (dénombrements aux barrières) mais ne constituait que de 20 à 48 % de l'echappee probable (estimation par marquage-

recapture selon le théorème de Bayes). Les estimations les plus précises sont celles obtenues du nombre maximum de saumons vivants plus le nombre cumulatif de saumons morts et de la surface sous la courbe. Les levés de frayères et d'une zone repère effectués dans les eaux d'amont réputées être des frayères ont donné des résultats semblables quand on a utilisé les mêmes méthodes de calcul, mais ces levés n'expliquaient qu'une petite fraction de l'échappée probable.

L'indexation de l'échappée en milieu fluvial suppose une relation connue ou fixe entre les indices et l'échappée. Toutefois, le manque de données ne permet pas d'étayer cette hypothèse en ce moment.

INTRODUCTION

The need for improved methods of estimating the escapements of Pacific salmon has recently been emphasized by the Commission on Pacific Fisheries Policy (Pearse 1982). Improvements to escapement estimation may take the form of new methodologies or the standardization and amelioration of existing methodologies. Currently, escapement data on approximately 1800 salmon streams are reported annually. The great majority of these data are obtained as visual estimates based on foot surveys by fishery officers (Waldichuk 1984). The escapement data may vary considerably in accuracy and precision, because of the different techniques used in their estimation, and the varying conditions under which the estimates are made. In most instances neither the accuracy nor the precision of the individual estimates are known, nor are the factors influencing the accuracy and precision well identified.

The methods used by fishery officers to make escapement estimates are poorly documented at present (Anon. 1986). In practice, much of the current escapement data is generated by instream escapement indexing in which counts on certain segments of a stream are used as indicators of the abundance of salmon in the entire stream. These indicator stream sections may be spawning areas, or holding pools, or simply areas of the stream that are accessible to the observer: however, the entire stream will rarely be systematically surveyed to give a total count. The counts from these sections (index reaches) should indicate trends in relative abundance and may, under certain assumptions, be used to estimate the escapement to the stream. Even in cases where it is possible to make visual surveys over the entire stream, surveys on smaller areas may greatly reduce time and manpower requirements, while providing explicit variance estimates for the resulting escapement estimates. Instream indexing using visual count data from foot surveys may be particularly useful for estimating coho (Oncorhynchus kisutch) escapements, since spawning coho are frequently widely dispersed over the headwaters areas of many small streams where other enumeration methods are impractical.

Instream indexing of escapement is conceptually similar to stream indexing (Symons and Waldichuk 1984), which uses measurements of escapement in an index stream to predict escapements in nearby and "similar" streams (Waldichuk 1984). The assumptions which underlie instream indexing and stream indexing are similar: both require a high correlation between numbers in the index areas and the areas to which the results are to be extrapolated. The utility of stream indexing has been critically assessed (Symons and Waldichuk 1984) and is the subject of ongoing research. Stream indexing forms the basis of the management of some Oregon and Washington salmon

stocks (Zilliges 1977; Flint 1984; McGie 1986). Instream indexing, however, is intuitively the more useful concept, since the required correlation between stream sections seems more likely than the correlation between different streams. Beidler and Nickelson (1980) and Flint (1984) examined the correlation between known escapements of coho and counts on index areas, with no clear conclusions. Comparisons of spawning ground counts against fence counts and mark-recapture estimates (Crone and Bond 1976) give additional information on the relationship, but there does not appear to be a published time-series of sufficient duration and amplitude to permit an assessment of the basic assumptions of instream escapement indexing.

We have attempted to evaluate the utility of instream indexing for coho escapements by applying it to a small river system for which there were independent estimates of escapement from fence counts and mark-recapture surveys. Our approach is methodological: we compare (1) different foot survey designs, and (2) methods of calculation, using visual-count data against known escapements. We also examine some of the factors which influence the visual counts. In the short term, the resulting data may give guidance to fishery officers in their selection of enumeration methods; in the long term, the accumulation of data over a number of years may allow a test of the assumptions of instream indexing.

Our consideration of survey designs is motivated by the practical requirements of fishery officers: we wish to identify simple designs which can be applied widely to allow a rapid and accurate enumeration of spawning coho in selected reaches that reflect abundance in the entire stream. Thus we consider the location, size, and number of survey units. The choice of an appropriate survey design may depend on factors such as access and prior knowledge. For instance, the Oregon and Washington coho stream indexing programmes appear to use surveys of variable length on the spawning grounds. Such a design requires both a detailed knowledge of spawning areas and ready access to the locations. Foot surveys may be constrained by lack of knowledge or lack of access. We consider three survey methods which differ in their choice of sampling units, depending on access and prior knowledge. We designate these three designs as (1) spawning ground surveys, (2) random surveys, and (3) "index area" surveys.

The three designs differ in their definition of the sampling universe and method of sampling. Spawning ground surveys define the sampling universe to be the known and presumed spawning areas, from which a random sample of survey units are drawn. Inferences based on the sample then refer to the collection of possible sampling units on the spawning grounds. Spawning ground surveys have several potential advantages over other designs. Indices or estimates of abundance based on spawning ground surveys refer directly

to the population of spawners, which is presumably the population of interest to managers. Because spawning coho may be more visible, fish densities higher, and the streams smaller in spawning areas, spawning surveys may be faster and more precise than surveys in other areas. However, because coho often spawn in small headwater streams, a knowledge of and access to spawning areas may be lacking.

Simple random sampling over the whole stream may be appropriate where little is known about the distribution of spawners or where spawning occurs widely throughout the stream, but access to specific sites is possible. Simple random sampling may be statistically inefficient; however habitat-stratified random sampling may be possible. We have not compared habitat-stratified random sampling since detailed information on habitat distributions would not be available in most river systems, and was not available for French Creek. The average density of fish obtained by simple random sampling over the whole stream may be used directly as an index of relative abundance without requiring further assumptions regarding the proportion of the escapement using the survey areas, unlike other designs.

Lack of access may limit the areas available to foot surveys in some streams. Under such conditions, accessible areas which are regarded as more-or-less "typical" of the stream may be surveyed. We designate such surveys as "index area" surveys. Index areas are extensively used; in Washington, index areas are "usually easily accessible, have good visibility throughout most of the spawning season, and are considered representative of total escapement to the stream" (Zillges 1977, p.4). Because the counts obtained on such survey areas are not a random sample of all possible sampling units in the stream, the average density of fish on the survey areas does not estimate the average density in the stream. The count data from the survey areas can then be used as an index of relative abundance only if the ratio of counts on the index area to the total escapement is known or is constant. It should be noted that the same comments would apply to spawning ground surveys if the sampling units were not randomly chosen. Beidler and Nickelson (1980) consider some of the assumptions that must obtain for the data to represent an index of abundance.

The size of the survey unit that is sampled will influence the cost and precision of the resulting estimates. The sampling units may be natural units which vary in size, such as spawning reaches, or they may be artificial units defined by the surveyor. Spawning reaches between 0.4 and 5.0 km have been used in the Oregon index (Beidler and Nickelson 1980). We compare sampling units from 100 to 700 m in length.

If visual counts are to be used as indices of relative abundance, counting efficiency of different surveyors must be

constant among surveys, or the relative efficiencies known. If the counts are to be used as estimates of absolute abundance, then the absolute counting efficiency must also be known. There have been several comparisons among different surveyors (Sheridan 1962; Willis 1964; Shardlow et al. 1987) which suggest that different surveyors count similar numbers of fish. However, there appear to be few estimates of the absolute efficiency of surveyors. Solazzi (1984) found that visual counts were about 75% of true numbers of adult coho in small spawning streams and that environmental variables had little influence on counts. Because of their importance to escapement estimation, we have also examined the relative and absolute efficiency of visual counts and the effects of physical variables on the counts.

A number of indices of abundance can be constructed from a time-series of visual counts. Possible indices include average live plus dead count, peak live count, peak live count plus dead accumulated to that time, accumulated dead count, and the area under the counts-versus-time curve (Cousens et al. 1982; Flint 1984). Flint (1984) compared some of these against fence counts and suggested that peak live counts were the least variable index. We examined the accuracy and precision of escapement estimates based on the above indices of coho abundance.

MATERIALS AND METHODS

SITE DESCRIPTION

French Creek (RAB No. 92-3700) is a small stream on the southeast coast of Vancouver Island (Fig. 1). It arises on the eastern slopes of Mount Arrowsmith and flows northeast for about 20 km to enter the Strait of Georgia near Parksville, British Columbia. Brief descriptions of the stream are given in Brown et al. (1977) and Hancock and Marshall (1985). The creek bifurcates into two major branches about 12 km upstream (Fig. 1), with the West Fork being impassable to fish about 400 m above the confluence. The lowermost 16 km of the south fork are accessible to anadromous coho (our observations).

Coho and chum (O. keta) salmon spawn in the creek. The estimated coho escapement has varied between 50 and 3500 fish in recent years (Hancock and Marshall 1985). Coho spawn throughout the creek but the greatest abundances are generally noted upstream of Coombs, especially in the headwater areas in the vicinity of Winchester Road and in the BC Forest Products' tree farm (Department of Fisheries and Oceans files, Qualicum Beach). Chum salmon are much less abundant (2-250 fish recently) and spawn in the lower reaches of the creek. Resident populations of trout (Salmo gairdneri)

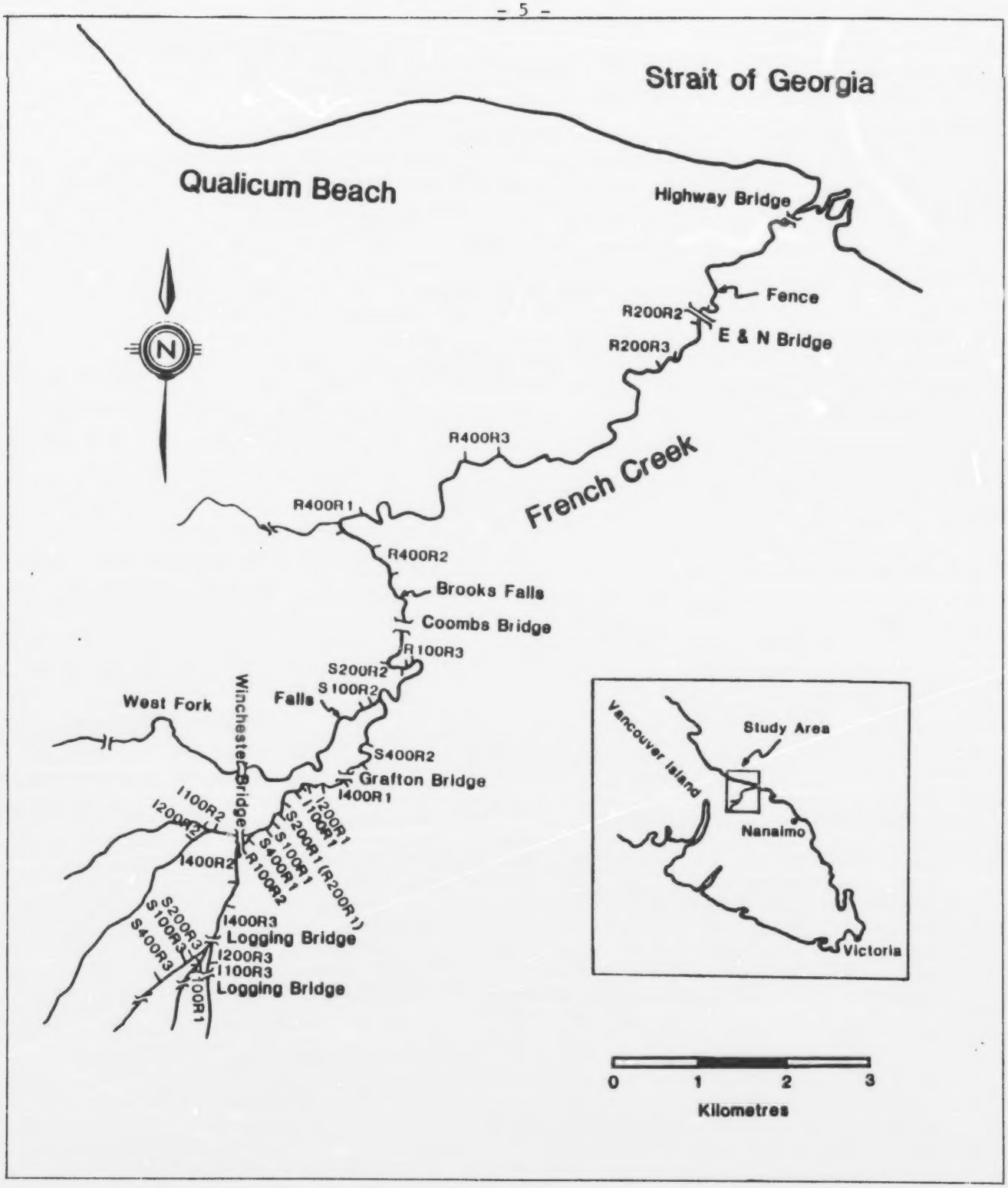

Figure 1. A map of the study area, showing the locations of the sampling sites.

occur throughout the stream.

The creek varies in width from a few metres in the headwater feeder streams to about 15 m in the lower reaches. It is shallow, with depths typically less than 50 cm. Pools can be up to 2 m deep in the lower river. Flows vary irregularly depending on rainfall. The stream is subject to freshets during the winter rainy period but often goes dry in late summer. Our data suggest discharges of 5-10 $m^3 \cdot s^{-1}$ from November to January. The streambed tends to be coarse gravels and small boulders, with areas of larger boulders and bedrock. The surficial geology consists of glacial tills and marine gravels with outcroppings of sandstone bedrocks around Coombs (Fyles 1963). Streambank erosion occurs throughout. Gravels suitable for spawning were most evident above the West Fork junction, but were noticeably compacted with fines after the first freshet. Several small waterfalls and areas of bedrock between the Brook's Falls fish ladder and the West Fork confluence may impede fish passage at times.

Land use changes considerably along the stream. The lowermost 2 km flow through residential housing. The stream is bordered by farmland above this to Coombs, and by hobby farms and rural residences between Coombs and the B.C. Forest Products' tree farm, which contains the headwaters of the creek. Access to the stream is very good. Streamside vegetation consists of a canopy of broadleaf maple (Acer macrophyllum) and large alder (Alnus sp.) in the lower reaches and Douglas fir (Pseudotsuga menziesii) in upper areas. The understory is mixed shrubs.

EXPERIMENTAL DESIGN

We wished to compare the precision of indices of relative abundance, and the accuracy and precision of estimates of escapement, obtained from visual counts using different sampling designs (spawning ground surveys, simple random sampling, "index area" sampling), sampling unit sizes (100, 200, 400 m), and methods of calculation (peak live counts, peak live plus accumulated dead counts, area-under-the-live-count curve, and total dead counts).

To define the sampling universes for the various survey designs, the entire stream was surveyed during the late summer dry period to locate access points and areas whose gravel characteristics indicated potential spawning grounds. Spawning areas were identified from this survey, from DFO files and maps, and from discussions with local residents. Index areas were defined as "typical" stream sections between well-defined access points (road crossings) in the headwater areas above the West Fork. The sampling universe for simple random sampling was defined by dividing the stream length

above the UBC-DFO counting fence (which was located approximately 2 km from the rivermouth) into 100 m sections using 1:10000 scale (Nanaimo Regional District) and 1:50000 scale (National Topographic Series) maps. Survey sites were located in the field by measuring distances from known landmarks (road crossings) along the midchannel using a 50 m surveyor's tape, and were flagged for permanent reference.

For simple random sampling, survey unit size effects were examined using a completely randomized design ANOVA, where the three replicates of the three survey lengths were randomly chosen from the set of 100 m stream sections. Because spawning areas and index areas occurred as natural units, which would be expected to vary among locations, the effects of sampling unit size were examined separately for these survey types, using a randomized complete block ANOVA design with locations along the stream as blocks and survey unit lengths as the treatments (Fig. 1). Three blocks of 700 m length were chosen for both spawning area and index area surveys, and three survey units of 100, 200, and 400 m length randomly assigned within each block. For the spawning area survey design, only two blocks of 700 m were available so that the third block was actually comprised of three non-contiguous but nearby survey units which were spatially well separated from the other blocks. Surveys were conducted as described below.

Peak live counts, peak live plus accumulated dead, total dead, and area-under-the-curve (AUC) indices of abundance were calculated from the count data, as decribed below. Because variances and means proved correlated, the data were transformed as $x^{0.15}$, which was the transform obtained by applying Taylor's power law (Elliott 1977). Transformed means were compared using Tukey's test (Zar 1984). All analyses were performed using the MIDAS statistical package (Fox and Guire 1976) and GENLIN general linear model (Greig and Bjerring 1980) at the UBC computing centre.

The relative precision of the indices of abundance derived from the visual counts from the various survey designs were determined by comparing unbiased coefficients of variation (Sokal and Rohlf 1981). The accuracy of escapement estimates derived from these indices was compared to the coho escapements estimated from fence counts and mark-recapture data (Labelle 1987). The mark-recapture estimate was derived using a sequential Bayesian method (Gazey and Staley 1986) which greatly reduces the sources of bias associated with simple Peterson type estimators. Because the fence had to be collapsed on two occasions because of high water (Labelle 1987), the fence count is a minimum escapement, while the Bayesian mark-recapture estimate is regarded as the most probable escapement.

FOOT SURVEYS

The 27 survey units were sampled six times between 19 November 1986 and 7 January 1987. Surveys commenced the day following the first passage of coho above the counting fence and continued at weekly intervals until 18 December, with a final survey in early January. The entrance of the coho run into French Creek was delayed by abnormally late winter rains, with the result that most (96 %) of the run moved upriver past the fence over a 2-3 day period (Labelle 1987). The last date that coho passed the fence was 10 December; the fence was removed on 16 December. Weekly survey intervals were chosen, since the average stream life of coho is thought to be between about 9 and 11 days (Nickelson et al. 1986; van den Berghe and Gross 1986).

The visual counts were done by a two-man crew walking in the stream. The pair of observers carried 2 m poles to dislodge coho from cutbanks and other hiding places, and progressed together, one on each side of the stream. The observers worked together as a unit, with one being positioned to note the appearance of fish when the other probed refuges. Counts were done from the upstream end of the survey unit downstream. Coho densities were low enough that the movements of individual fish could be followed when they were disturbed, so that double counting was unlikely. Surveys were done under conditions of moderate flow and good visibility, except for the first week when high flows necessitated that some surveys be done from the bank. The locations of live coho, carcasses, and redds were marked on 1:10000 maps of the survey units. Carcasses were measured and examined for marks. All surveys of a given type (random, index, spawning) were generally completed in a single day.

PHYSICAL HABITAT VARIABLES

To determine the effects of physical factors on the observed numbers of coho, we measured stream width, average depth, current speed, water temperature, visibility, and substrate composition on each of the survey units. Substrate composition was determined at 50 m intervals along the survey units during the early October dry period by running a surveyor's tape between the stream banks and scoring the dominant substrate category in each 0.5 m segment, using a modified Wentworth classification (Armour et al. 1983). Substrate coarseness and heterogeneity were then computed as the mean and standard deviation of all segment scores on a sampling unit. The technique is similar to that suggested by Bain et al. (1985). The other variables were measured at the top and bottom of each unit on each survey date. Wetted stream width was measured to the nearest 0.1 m by running a surveyor's tape across the stream, and depths measured to the

nearest cm at 1 m intervals along the tape. Approximate current speeds were determined by timing a floating twig over a measured distance along the midchannel; two or three determinations were averaged. Water temperature was measured to the nearest 0.5°C with a pocket thermometer. Visiblity was measured with a 10 cm diameter Secchi disk with alternate white and black quadrants which was attached to a graduated staff. In most cases the visibility exceeded the greatest water depth so that only visibility classes (0.75 to 1.0 m, 1.0 to 1.25 m, >1.25 m) could be scored. The stream size, depth, and current speed data allow the calculation of an approximate discharge as current speed times cross-sectional area. The influence of these variables on the numbers of coho observed per 100 m was determined by stepwise linear regression.

INTER-OBSERVER DIFFERENCES

We examined differences between observers in the counting of adult coho during foot surveys by having two pairs of observers independently count 14 sampling units. The surveys proceeded in the usual manner with the second pair of observers following the first at an interval of 10-15 minutes. Since the passage of the first crew might influence the counts of the second by causing the fish to seek shelter, the order of surveys was randomized by crew.

OBSERVER EFFICIENCY MEASUREMENTS

Observer efficiency was measured on 11 occasions by determining the actual numbers of coho present on survey units that had been counted in the usual manner. The actual numbers of coho present were estimated by electrofishing the stream sections using a backpack electroshocker. Immediately after a survey unit had been counted in the usual manner, a separate two-man crew electrofished the unit. Neither crew knew the other's count. Although the survey units were not sealed to fish movements, it is unlikely that numbers changed since the measurements were done within minutes of one another, fish generally were not moving upriver, and the electrofishing crew progressed upstream to reduce the effects of the possible upstream movement of fish. Virtually all coho detected by the electroshocking were captured in a scoop net and marked to avoid double counting, and most fish moved downstream after being released. We feel that the electrofishing estimates were quite accurate in the rather small, shallow, spatially simple headwater stream sections.

ESCAPEMENT CALCULATIONS

The foot survey data were standardized to counts per 100 m and the following indices of abundance calculated for each survey unit: (1) peak count of live fish, (2) peak count of live fish plus the count of dead fish accumulated to that time, (3) total count of dead fish accumulated over the entire survey period, and (4) the area under the live count-time curve (AUC). The method for calculating the AUC is described by Beidler and Nickelson (1980) and Ames (1984). Since we knew the date of entry of the fish, the integration of the AUC commenced on that date.

Escapements were determined as the population totals estimated by single-stage cluster sampling, with clusters of unequal size (Cochran 1977, p.250), since the sampling units varied in size but were randomly selected. In our case, survey sites correspond to clusters and 100 m sections within surveys are the elements in the population. The estimation of the population totals requires that the total number of elements in the population be known, that is, that the number of 100 m elements in the stream reach be known. The estimated population total is then the sample mean per element times the total number of elements. For our simple random sampling, this was the number of 100 m sections in the stream length above the counting fence, while for the spawning ground and index sampling the stream length above the West Fork confluence was used. Stream length was measured from maps as far as the Winchester Road bridge and by measurement in the field above this point to the observed limits of coho distribution, as maps were inaccurate in this section. There were 72 elements above the West Fork and 177 in total. The variance estimates require the number of clusters in the population, which was estimated as the number of elements in the population divided by the number of elements sampled in n clusters, times n. For the index sampling, the clusters consisted of the three 700 m blocks; for the spawning ground sampling, the clusters were the two 700 m blocks and the non-adjacent 100, 200, and 400 m survey sites; for the simple random sampling, the clusters were the 9 survey units. The estimated population totals were then scaled by the observer efficiency value that we had measured to give escapement estimates. The AUC estimates were further divided by an average stream life to give the escapement. The average stream life was estimated from coho in the nearby Little Qualicum River spawning channel by dividing the accumulated live fish-days by the known escapement to the channel.

RESULTS

The numbers of coho observed on the spawning ground, random, and index area sampling units throughout the study period (Appendix 1) peaked in early December, several weeks after the coho run moved upriver (Fig. 2). Coho appeared in the headwater spawning areas within three days of passing the counting fence and remained at approximately constant densities in these areas until mid-December. Abundance changes were most pronounced on the index and especially on the random sampling units, but fish densities were low everywhere. Peak densities averaged between 0.33 and 3.6 fish per 100 m, and the maximum density observed on any individual survey unit was only 7 fish per 100 m. Variance to mean ratios calculated for counts from the 3 replicate units of each size and survey type for each survey period implied that the coho were randomly distributed at the spatial scale of our sampling (chi square test, $p<0.05$, Elliott 1977). However the 400 m random survey unit data often showed a clumped distribution, which apparently resulted from high counts on a unit several hundred metres below the Brook's Falls fish ladder. Our observations at the falls suggest that coho passage was impeded or delayed at high flows. All three survey types showed similar patterns of abundance through time (Kendall's coefficient of concordance=0.929, $p=0.0001$) which suggests that our sampling reflected the broadscale distribution of the fish throughout the areas sampled. A single jack coho was seen.

Few carcasses were recovered (Appendix 2). Seventy percent (24 of 34) of the carcasses were found at or after the period of peak live counts and were primarily spawned out fish. Those found prior to the live count peaks were often predator kills, especially by otters (Lutra canadensis) in the lower river. Carcasses account for only about 20% of the live fish seen, which suggests that carcasses may remain observable for about 2-3 days on average (compared to 10-15 days for live fish). Few redds (7) were found during our sampling. Most of these were in the headwater areas between the West Fork confluence and the second set of logging bridges in the BCFP tree farm: however, several were found in a pool tailout in the lower river about 4.5 km above the counting fence. Thus some spawning occurs throughout the creek, although without obvious areas of aggregation. We surveyed several of the tributaries in the middle and upper reaches at irregular intervals without finding spawning fish. Evidently spawning was confined to the mainstem river. Redds did not remain observable between weekly surveys, perhaps as a result of the scouring and sediment transport noted after freshets.

Indices of coho abundance derived from the weekly surveys are given in Table 1. The peak live counts, peak live plus accumulated dead, and AUC are significantly correlated

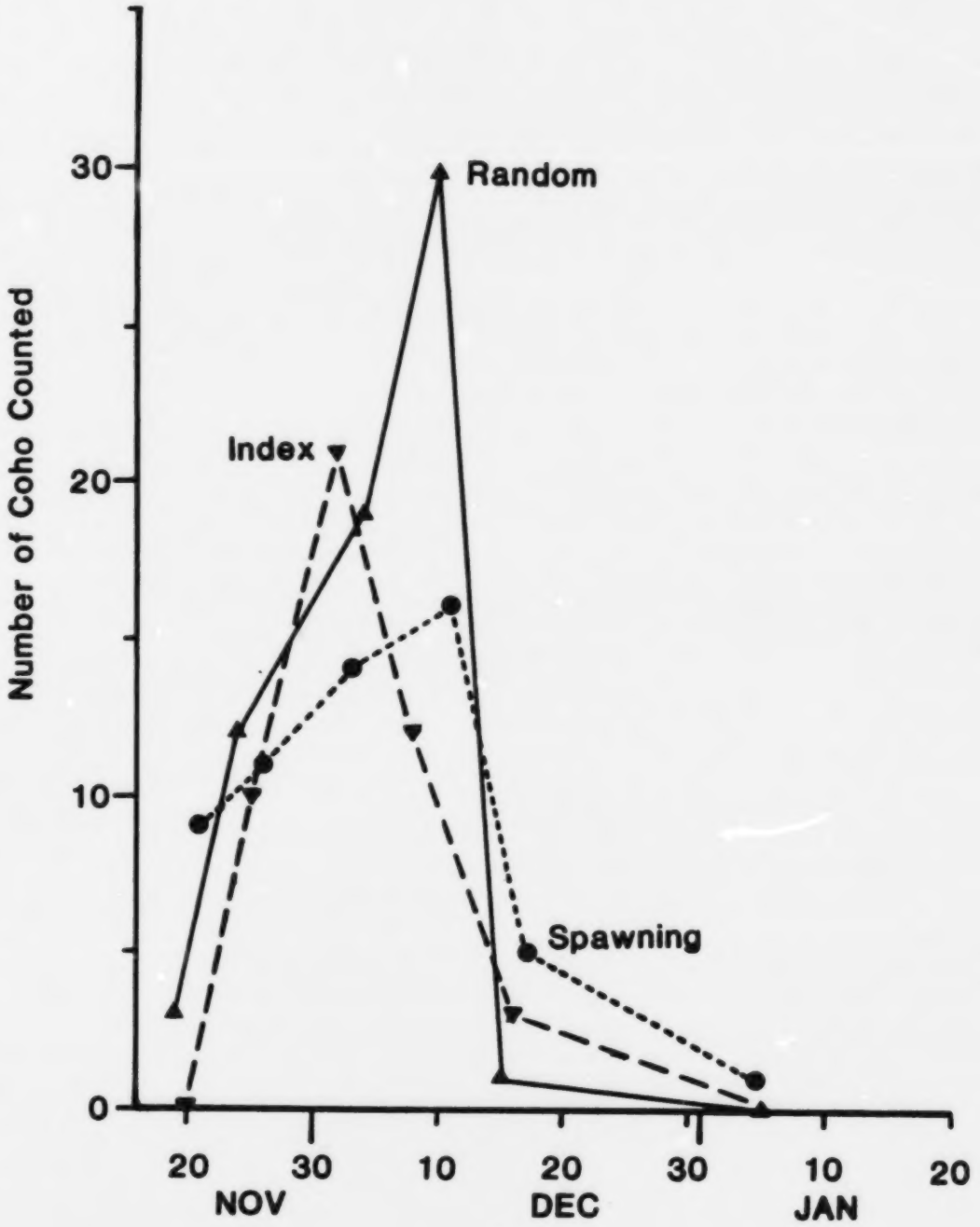

Figure 2. The numbers of adult coho counted on random, spawning ground, and index area surveys in French Creek between November 1986 and January 1987.

Table 1. Indices of adult coho abundance derived from visual counts (means, and SD in brackets, n=3). Data are in numbers per 100 m, except AUC which is in fish-days per 100 m. Underlined means form homogeneous groups at p=0.05 (Tukey's test).

Abundance Index	Survey Type	Length (m) 100	200	400	Prob
Area-under-curve	Spawning	59.8 (68.6)	14.3 (12.9)	12.5 (12.1)	ns
	Random	0	6.3	35.4	0.02
		0	(7.6)	(39.0)	
	Index	4.2 (7.2)	13.3 (5.0)	19.7 (9.2)	ns
Peak live count	Spawning	3.67 (2.88)	0.83 (0.57)	0.75 (0.43)	0.001
	Random	0	0.67	2.50	0.02
		0	(0.76)	(2.61)	
	Index	0.33 (0.58)	0.83 (0.58)	1.50 (1.09)	ns
Peak live + dead	Spawning	3.67 (2.88)	1.00 (0.87)	0.92 (0.29)	0.008
	Random	0	0.83	3.42	0.02
		0	(0.76)	(3.36)	
	Index	0.33 (0.58)	0.83 (0.58)	1.58 (1.01)	ns
Total dead	Spawning	0 0	1.00 (1.73)	0.25 (0.25)	ns
	Random	0	0.83	1.08	0.03
		0	(1.04)	(0.80)	
	Index	0 0	0.17 (0.29)	0.42 (0.38)	ns

with one another ($p<0.05$), but not with the total dead counts. Abundance indices derived from counts on 200 and 400 m sampling units were statistically indistinguishable within any survey design (Table 1). However, the indices calculated from spawning ground surveys were higher on the 100 m units than on the larger units, while indices for the 100 m random surveys were lower than those calculated from 400 m surveys, but were indistinguishable from the 200 m results (Table 1). All the abundance indices had poor precision. Unbiased coefficients of variation ranged between 34 and 190%, with typical values being about 100%. Coefficients generally decreased with increasing sampling unit size. However, none of the coefficients was statistically different from another. The precisions of indices calculated for spawning ground and index area surveys were usually better than random surveys. For spawning surveys, peak live counts were the most precise index. Peak live plus dead counts were the most precise index for random surveys, and AUC for index area surveys.

The numbers of coho counted by the two different field crews on the same set of sampling units (Appendix 3) were highly correlated ($r=0.88$, $n=10$, $p<0.05$). The counts did not differ between teams of observers (paired t-test, $p=0.17$), nor between the first and second team to count a site (paired t-test, $p=0.66$).

The densities of live coho observed during our foot surveys were significantly correlated with the numbers estimated by electrofishing ($r=0.93$, $n=11$, $p<0.05$, Fig. 3), but were usually one or two fish lower (Appendix 4). To develop a predictor of the actual density of coho on the survey units and to assess the influence of physical parameters (Appendix 5) on that density, we regressed the coho densities that were estimated by electrofishing against those determined by visual counts and against visibility, mean water depth, mean stream width, current speed, mean substrate coarseness, and substrate heterogeneity using a stepwise selection procedure with a p-to-enter of 0.05. The actual density depended only upon the visual indices of density, the physical variables making no further contribution ($p>0.05$). The best linear fit to the data passed through the origin and accounted for 87% of the variance. The regression slope estimate of the ratio of observed densities of adult coho to the densities actually present was 0.69 ($\pm$ 0.15, 95% CL).

The simple linear relationship between visual counts and the actual densities of coho may be biased by correlations among the set of independent variables which could reduce the importance of any one variable. The physical variables which relate to stream characteristics arise through the common influence of discharge and are highly correlated. To remove the effects of multicollinearity in the predictor variables, we repeated the stepwise regression

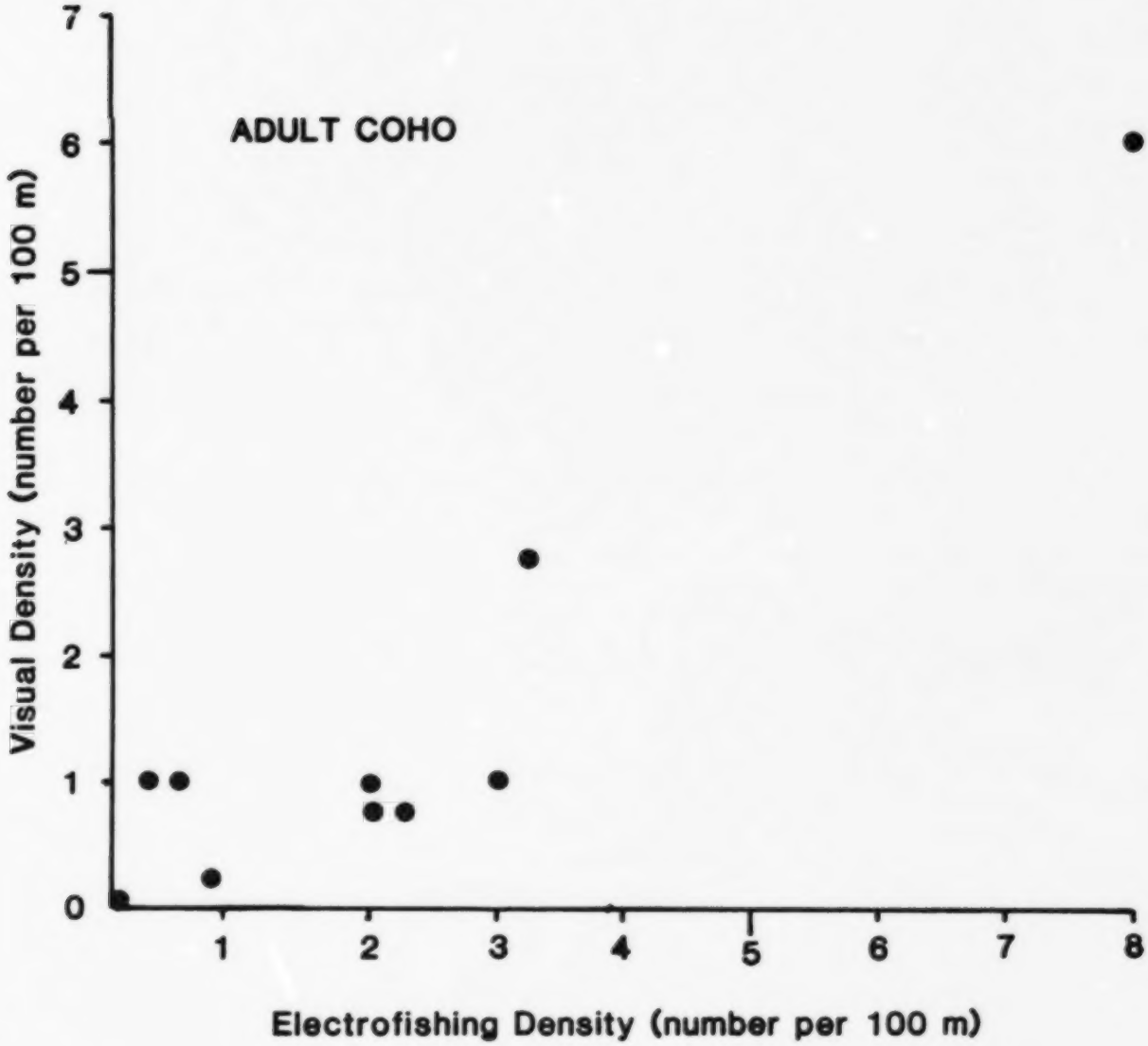

Figure 3. The relationship between the densities of adult coho estimated by electrofishing and by visual counts.

using principal components obtained from the correlation matrix. Only the principal components that accounted for more than 1 % of the total variance were included as potential predictor variables (Joliffe 1986). Because the principal components are linear combinations of the standardized original variables, the relative influences of the original variables can be compared by multiplying the regression coefficients for those principal components that appear in the regression model by the coefficients of the original variables that comprise the principal component, and summing. The principal components and regression model are given in Appendix 6. The regression model accounted for 80% of the variance in actual coho densities. The visual estimate of density was the most important contributor to the predicted density, with a coefficient several times larger than those of the remaining variables. The results confirm that visual counts can be used to estimate actual densities of coho.

Knowing that the densities determined from the visual surveys are proportional to the true densities of coho, we examined the effects of physical factors on the distribution of coho using the much larger set of visual survey data. Once again we constructed principal components from the correlation matrix of the physical variables to eliminate multicollinearity in the independent variables, and used a stepwise regression procedure to build a predictor of coho density. The results are given in Appendix 7. The model accounted for only 11% of the variation in the visual indices of coho density. The low predictive power of the model suggests that the observed densities of coho were not simply related to the physical features recorded by us in French Creek.

Estimates of the coho escapement and the population total upstream of the West Fork confluence are given in Table 2. The AUC estimates have been calculated using a mean stream life of 13.3 days determined from data for the Little Qualicum River spawning channel (Appendix 8). The measured observer efficiency of 0.69 has been used to adjust visual counts to the actual numbers of coho present in the calculation of the population totals.

The number of adult coho known to have passed upriver of the counting fence is 558 while the Bayesian mark-recapture estimate of the escapement above the fence is 1153 fish (Labelle 1987). The estimates of the escapement obtained from our random sampling account for 42-100% of the minimum known escapement, but only 20-48% of the most probable escapement. The AUC and peak live plus accumulated dead count estimates were similar and were considerably higher than estimates derived from the peak live count and total dead count, but the precisions of all the estimates were poor. Coefficients of variation for the escapement estimates were about 50% for all methods of calculation.

The estimates of the total number of coho in the area upstream of the West Fork confluence, which was presumed to be the major spawning area in French Creek, accounted for only a small portion of the probable escapement (Table 2). The total numbers of coho estimated from our spawning ground surveys were about 8-37% of the minimum escapement and 4-18% of the probable escapement. The estimates from index areas in the same region were similar. Both sets of estimates were generally more precise than estimates obtained from random surveys. The total dead count data once again gave the lowest and the AUC estimates the highest population totals but the AUC estimates were proportionately much higher for these survey units above the West Fork than for the whole river.

Table 2. Estimates of the population totals (SD in brackets) for the different survey designs and methods of calculation. The values for random surveys estimate the coho escapement while those for spawning ground and index area surveys estimate the number of coho above the West Fork confluence.

Method of Calculation	Survey Design: Random	Spawning	Index
Peak live count	367 (213)	79 (18)	105 (44)
Peak live + acc. dead	538 (271)	94 (19)	105 (44)
Total dead count	232 (69)	45 (24)	30 (7)
AUC	557 (300)	205 (67)	160 (37)
Fence count (minimum escapement)	558		
Mark-recapture estimate (probable escapement, Labelle 1987)	1153 (968-1492, 95% CL)		

The precisions quoted above for the population totals do not account for uncertainty in parameters such as observer efficiency or average stream life which are used in the estimation of the absolute number of coho. Since the parameters themselves have large measurement uncertainties, the true precisions of the population totals will be rather worse than stated.

DISCUSSION

The use of any index to represent the relative abundance of a population assumes that the index bears a known relationship to the abundance. While it is generally assumed that the index represents some constant proportion of the population, it is essential that the relationship between the index and abundance level be established.

Instream indexing for salmon escapement estimation has assumed that indices of abundance are directly proportional to abundance. Thus, for example, index counts have been calibrated to abundance in a base year and used to estimate escapements in subsequent years (Flint 1984). However there are few published data to demonstrate the assumed proportionality. Beidler and Nickelson (1980) found that weir counts of coho and peak counts on standard areas were poorly correlated and that different indices also were poorly correlated. Flint (1984) found that several indices were highly correlated with weir count and mark-recapture estimates of escapement in Harris Creek, Washington ($r=0.989$ for AUC, $r=0.987$ for peak live, $r=0.993$ for peak live plus dead, $n=4$, $p<0.05$, calculated from his Table 1), but that the ratio of index values to actual escapements varied considerably among years ($\pm$ 20 to 40% of the mean ratio).

Indices of escapement that are derived from visual counts obtained in foot surveys on standard index areas must assume that (1) the proportion of the run using the index area is constant among years, and (2) that the probability that a given fish be seen is constant or known among observers and among years. Factors affecting the ability of observers to detect fish have been studied and are discussed below. However it is likely that the utilization of particular stream sections will vary with population levels, especially if spawning areas are surveyed (Mundie 1984). This is suggested by Flint's (1984) data, where the ratio of the indices for the tributary and mainstem survey areas varied between 0.42 and 1.19 over four years which had a 5-fold variation in escapement, and where the proportion of the escapement observed on the index areas increased with increasing escapement. There is a need for time series of data comparing index values and known escapements over a range of population levels in several streams to assess the relationship between counts on index areas and actual escapements. This is especially true if managers wish to use the indices to estimate absolute rather than relative numbers of spawning fish.

If the above assumptions hold, then instream indexing of escapements allows survey areas to be arbitrarily defined. The ability to locate survey units non-randomly may be an important advantage where access to certain stream sections is difficult or where prior knowledge allows areas of high

use to be identified. However, the surveyors lose the ability to monitor even relative abundance if the assumed proportionality to escapement does not hold, since the resulting counts will be biased estimators of the mean density per survey unit. In contrast, counts from randomly located survey units can always be used as measures of abundance for the sampling universe from which the units are drawn. Consequently, it would seem advisable to count randomly assigned survey units, unless there is compelling evidence that the proportion of the escapement found on an arbitrarily defined index area is constant.

There are other sampling designs that can be used in place of simple random sampling (SRS). If the primary sampling units (e.g. tributaries) vary in size, units may be selected with a probability proportional to their size (PPS sampling). Cochran (1977) gives the theory while Hankin (1984) provides an example and a comparison of several designs. However, PPS sampling designs are subject to the same potential constraints (e.g. access) as is SRS; in practice, logistics may necessitate non-random sampling.

Our comparisons of survey unit sizes suggest that the precision of all commonly used indices increased with survey length over the range from 100 to 400 m. Abundance indices expressed on a density basis (number per 100 m) also varied among survey unit sizes, with different patterns of variation being evident for different sampling designs. Indices were highest for the smallest size (100 m) in spawning ground surveys but were higher for the larger sizes in random sampling. Presumably, these results reflect the spatial dispersion of the fish. Spawning areas in French Creek appear to be small, so that larger sampling units within the general region of spawning will incorporate areas of lower use. In general, the precision of indices from spawning ground and index area surveys were better than those of randomly located surveys. The non-random choice of sampling units in the former cases effectively resulted in more homogeneous samples.

Flint (1984) found that peak live counts were the least variable index of relative abundance of coho in Harris Creek. We found that the precision of a particular index using a given sampling unit size varied with the sampling design. For spawning ground surveys we also found peak live counts to be the most precise index. For random surveys, peak live plus accumulated dead counts gave more precise index values while AUC indices were more precise when index area surveys were considered. The reasons for these differences are not obvious. However it is clear that the choice of an appropriate index will depend upon the survey design. Since the coefficients of variation were approximately 100% for all the indices of coho density (Table 1), about 16 samples would be required to obtain a mean index which is accurate to $\pm$25%

with a 5% chance of type I error, and about 100 samples for ±10% precision. This suggests that indices of abundance based on visual counts may be imprecise under usual sampling designs where few counts are possible.

The estimation of the absolute size of the escapement from surveys on index areas presents special problems. If the index is directly proportional to the escapement, then the escapement can be estimated from the index using the known relationship between them. The accuracy of such an estimate will depend upon the accuracy of the relationship used: Flint (1984) showed that widely varying estimates were obtained when different base year escapements were used to calibrate escapement indices.

If the relationship is not known then standard statistical inference is the only recourse, which necessitates random sampling. Stratified simple random sampling may be advisable if areas of widely varying density can be recognized. Techniques for estimating a population total when sampling units vary in size, as will often be the case in foot surveys, are discussed by Cochran (1977) and Hankin (1984). Our estimates of the coho escapement in French Creek used a ratio estimator based on single-stage cluster sampling. The use of this method was appropriate, because the sampling units varied in size but were randomly sampled, because the fish were enumerated rather than estimated, and because the sampling unit totals and variances increased with increasing sampling unit size. The population estimates which we obtained varied considerably in accuracy depending upon which method was used to make the estimate. The peak live plus accumulated dead count and the AUC methods gave similar estimates which were about 48% of the actual escapement (as estimated by mark-recapture methods, Labelle 1987). These estimates compare favourably to the fence count of 558 coho. Where fences cannot be operated continuously throughout the coho spawning migration, estimates based on visual surveys may be as accurate as fence counts. Crone and Bond (1976) similarly found AUC and (incomplete) fence count estimates of coho escapements in a small Alaskan stream both to be about one half of mark-recapture estimates. We found that escapements calculated from peak live counts or total dead counts to be much less accurate than the two other methods. However, the precisions of all the escapement estimates were poor, the CV being about 50%.

The estimation of indices of relative abundance from visual count data requires that the proportion of fish counted be constant (or known), while the estimation of escapement requires that the proportion be known. Our data suggest that the number of coho detected in small headwater streams was constant between observers and was essentially independent of physical factors for the conditions under which we were able to make surveys. Several studies have

shown that different observers count similar numbers of salmon in foot surveys on spawning areas. Willis (1964) and Solazzi (1984) reported this for coho in headwater spawning streams while Sheridan (1962) demonstrated it for pink salmon. Shardlow et al. (1987) also showed that different observers obtained similar results if they had previous experience. Solazzi (1984) found that the proportion of coho detected did not change throughout the spawning period.

We observed about 69% of the actual density of coho present on survey units in headwater areas and found that the visually estimated densities depended only upon the actual density and not on physical factors. Solazzi (1984) found that observers saw an average of 75% of coho in headwater spawning streams. The relatively high proportion of coho detected during our surveys may result from the small size of the stream and from the manner in which we conducted our surveys. We used two observers who worked together as a team, we worked in the stream rather than from the bank, and we made a deliberate effort to dislodge coho from cutbanks and other hiding places. Much lower proportions will be seen under less favourable survey conditions. Shardlow (cited in Symons and Waldichuk 1984) reported that only 1.5% of known numbers of coho were detected in foot survey experiments on the much larger Big Qualicum River, where observers worked from the bank.

The confidence limits on our estimate of the proportion of coho seen were very broad, the limits being 54-84%. Solazzi's estimate was much more precise (±1.4%). It is not clear whether the lower precision of our estimate results from greater variability in the proportion of fish detected in our surveys or whether it simply results from our much smaller sample size. Uncertainty in the true proportion of fish seen will carry through to uncertainty in estimates of the escapement: the AUC escapement estimate of 557 fish obtained using an observer efficiency of 0.69 could lie between 458 and 713 if the precision of the efficiency estimate is considered.

The AUC estimates of escapement also require an estimate of the survey life (Ames 1984) of the fish to convert fish-days to numbers of fish. Survey life is usually approximated by stream life or breeding life (the time on the spawning grounds), depending on where the surveys are done and the behavior of the stock being estimated. Coho in French Creek began spawning immediately after entering the river so that breeding life is probably appropriate. We estimated survey life as the breeding life of coho in the nearby Little Qualicum spawning channel (13.3 days). Other values have been used elsewhere. Beidler and Nickelson (1980) used 11 days for Oregon coho stocks while Flint (1984) used 10 days for Puget Sound coho. van der Berghe and Gross (1986) determined an average residence time of 9 days for another Puget Sound coho

stock and showed that the breeding life varied with density and body size. Crone and Bond (1976) estimated breeding life as 11 days and 13 days in two successive years in a small Alaskan stream. Koski (1966, cited in Crone and Bond) found stream life to be 13.7 and 13.1 days in two small Oregon streams, while we found the average stream life of coho in the Keogh River, B.C. to be 11.4 days (Johnston et al. 1986). Thus plausible values of residence time could range between 9 and 14 days, which would produce a 50% range in the resulting escapement estimates. It is clear that measurements of the survey life of the stock for which the escapement is being estimated are needed if the AUC method is to be used. If the average survey life varies between years, as the data of Crone and Bond (1976) and of van der Berghe and Gross (1986) might suggest, then average survey life must be known to use AUC even as an index of relative abundance.

Mundie (1984) emphasized that measures of the relative abundance of animals should be interpreted with caution. We agree. If instream indexing is to be used to monitor the relative abundance of coho escapements, it is essential that the assumptions of the method be recognized and some attempt made to ensure that the assumptions are met. Ideally the assumptions should be tested on the specific stream to which the method will be applied. Failing this, we must have some assurance that the method is generally valid. At present there are insufficient data to be confident of the general validity of the technique, despite its current use.

The use of visual counts as an index of relative numbers presupposes a known, and we hope fixed, relationship between the index and the actual escapement. Variability in the relationship will determine the extent to which the index represents the underlying escapement values. Limited data from Washington suggest that the ratios of index values to escapements has a variation of about $\pm$20 to 50% (Flint 1984). If this is an acceptable degree of accuracy for the intended use of the data, then instream indexing of coho escapements may be a useful methodology. It is essential, however, that sufficient data be gathered to define the relationship between index values and escapements. The current assumption of a direct relationship is not well supported. Comparisons between index values and known escapements are needed over a range of abundance, both through time within single rivers and between rivers, to determine the generality of relationships between indices and escapements. Rivers with counting fences or with mark-recapture programs, which estimate the escapement, should routinely be surveyed to give indices of abundance.

The questions of survey design and which index to use are complex. Our data suggest that arbitrarily chosen index areas and spawning ground surveys were generally more precise than randomly located sampling units, and that larger units

were generally more precise than smaller units. The use of index reaches may thus reduce variability in the indices of abundance. However, data from non-randomly chosen index reaches cannot be used as measures of the relative abundance of coho if the relationship between index values and escapement varies, and will be biased measures if the relationship differs from that assumed. Conventional survey designs using SRS or PPS avoid the above problems, but may be impractical in some cases. Index reaches should be used only where the relationship between indices and escapements have been established.

Visual counts estimate the true densities of coho on small sampling units when surveys are made in small streams where observers can work in the stream and some effort is taken to find hidden coho. Physical factors such as water depth and discharge have little influence on the numbers observed if surveys are done under conditions of good water clarity and moderate flows. In small streams, such conditions are attainable. Surveys done from streambanks may be unreliable however. Differences in counts among observers are negligible if experienced observers are used.

We do not have data to compare the accuracy of different indices of abundance. Escapement estimates for French Creek that were derived from different indices all underestimated the known escapement. Escapements estimated using AUC and peak live plus dead counts were more accurate than peak live counts or total dead counts. However the use of AUC as an index of relative abundance or as an escapement estimate requires the estimation of an additional parameter (the survey life) which other indices do not need. The simpler indices may be preferable.

Our data indicate that it is possible to obtain accurate estimates of adult coho densities in headwater areas using visual foot survey techniques. However, it is necessary to use pairs of observers, to work in the stream, and to make an effort to dislodge coho from their hiding places. Different observers will produce similar estimates if they have at least some experience with the technique. Abundance estimates from larger sampling units are generally more precise than those from smaller units, which argues against using strip counts for coho enumeration. Non-random survey designs using spawning grounds or index areas may result in more precise indices of abundance; however, index reaches should be used only where the relationship between indices and escapements have been established. Otherwise, simple random sampling should be used. Peak live plus accumulated dead counts and area-under-the-curve indices are more accurate and more precise than peak live counts or total carcass counts. However, the AUC method requires the estimation of the stream life of the coho, which can vary between years and among stocks. Weekly surveys may be needed

to produce meaningful estimates of relative abundance of coho. It is essential that sufficient data be gathered to define the relationship between instream escapement indices and escapements.

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Appendix 1. Visual counts of live adult coho salmon in French Creek, 1986-87.

Survey Type	Unit Size (m)	Rep	Nov 19-21	Nov 24-26	Dec 02-04	Dec 08-11	Dec 15-17	Jan 05-07
Spawning	100	1	1	0	0	2	0	0
		2	1	3	7	4	3	0
		3	1	2	1	0	0	0
	200	1	1	0	0	0	0	0
		2	2	1	1	3	1	0
		3	1	1	0	1	0	1
	400	1	0	1	0	2	1	0
		2	2	1	5	4	0	0
		3	0	2	0	0	0	0
Random	100	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	200	1	1	3	1	0	0	0
		2	0	0	0	0	0	0
		3	0	0	1	0	0	0
	400	1	2	1	3	3	1	0
		2	0	8	13	22	0	0
		3	0	0	1	5	0	0
Index	100	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	1	1	0	0	0
	200	1	0	0	1	0	1	0
		2	0	1	1	1	0	0
		3	0	3	2	1	0	0
	400	1	0	2	4	3	1	0
		2	0	0	1	3	1	0
		3	0	3	11	4	0	0

Appendix 2. Counts of adult coho salmon carcasses in French Creek, 1986-87.

Survey Type	Unit Size (m)	Rep	Nov 19-21	Nov 24-26	Dec 02-04	Dec 08-11	Dec 15-17	Jan 05-07
Spawning	100	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	200	1	0	0	0	0	0	0
		2	0	0	0	1	5	0
		3	0	0	0	0	0	0
	400	1	0	0	0	1	1	0
		2	0	0	0	0	0	0
		3	1	0	0	0	0	0
Random	100	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	1
	200	1	0	0	0	0	1	0
		2	0	0	0	0	0	0
		3	0	0	1	2	1	0
	400	1	0	0	1	0	1	0
		2	0	0	6	1	1	0
		3	1	0	0	2	0	0
Index	100	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	200	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	1	0
	400	1	0	0	0	1	1	0
		2	0	0	0	1	2	0
		3	0	0	0	0	0	0

Appendix 3. Comparisons of visual counts of adult coho by two different observer teams in French Creek, 1986.

Date	Survey	Size	Rep	Team "A"	Team "B"	First Team
09 Dec	Spawning	100	2	4	1	B
	"	100	3	0	0	A
	"	200	3	1	0	A
	"	400	2	4	5	B
	"	400	3	0	0	A
	Random	400	2	22	10	B
	Index	400	3	2	0	A
	at West Fork			6	4	A
	below R400R2			0	0	B
10 Dec	Spawning	100	2	5	5	B
	Index	400	1	1	2	B
	"	400	2	0	0	A
	below I400R3			1	0	A
	at West Fork			2	3	B

Appendix 4. Comparison of visual and electrofishing counts of adult coho salmon in French Creek, B.C., 1986.

Date	Survey	Size	Rep	Visual	Electrofishing
02 Dec	Index	100	3	1	3
	"	200	3	2	4
	"	400	3	11	13
	"	400	2	1	3
	"	400	1	4	>1
08 Dec	Index	100	1	0	0
	"	200	1	0	0
	"	400	1	3	8
	"	400	2	3	5
	"	400	3	4	1
	Spawning	100	2	6	8

Appendix 5. Physical parameters for the survey units which contained adult coho, French Creek, 1986.

Survey	Discharge ($m^3 \cdot s^{-1}$)	Mean Depth (cm)	Mean Width (m)	Mean Current ($cm \cdot s^{-1}$)	Substrate Coarse -ness	Substrate Hetero -geneity	Secchi Depth (cm)
19-21 Nov:							
S-100-1	2.80	41	6.2	103	2.67	1.73	>125
S-100-2	2.84	45	8.0	76	2.38	1.65	> 85
S-100-3	0.47	15	3.0	82	3.89	0.74	> 95
S-200-1	3.65	29	11.2	107	3.45	1.31	>115
S-200-2	4.96	38	11.0	119	1.75	1.63	
S-200-3	0.65	18	3.6	88	4.25	0.83	> 95
S-400-2	3.57	24	11.8	129	3.81	1.47	>105
R-200-1	3.65	29	11.2	107	3.45	1.31	115
R-400-1	3.37	47	10.9	68	2.54	2.30	
24-26 Nov:							
S-100-2	4.10	49	8.7	96	2.38	1.65	
S-100-3	0.33	11	2.7	106	3.89	0.74	> 95
S-200-2	5.86	52	8.7	122	1.74	1.63	
S-200-3	0.69	15	3.5	106	4.25	0.83	> 85
S-400-1	3.27	29	6.2	160	3.86	0.95	>110
S-400-2	4.94	34	11.6	134	3.81	1.47	> 95
S-400-3	0.61	16	3.4	97	3.22	0.98	> 95
R-200-1	3.08	24	11.0	109	3.45	1.31	>115
R-400-1	5.58	54	11.2	93	2.54	2.30	
R-400-2	7.54	56	13.8	104	4.31	1.85	>105
I-100-3	0.59	22	3.3	88	4.95	0.65	>105
I-200-3	0.48	21	2.6	94	4.07	1.17	>105
I-400-1	3.09	40	6.8	114	2.69	1.76	> 75
I-400-3	1.26	28	5.2	80	3.89	1.09	>104
02-06 Dec:							
S-100-2	2.14	34	7.7	76	2.38	1.65	
S-100-3	0.29	11	2.8	87	3.89	0.74	> 85
S-200 2	4.27	36	11.0	106	1.75	1.63	
S-400-2	2.45	19	11.6	121	3.81	1.47	>115
R-200-1	3.45	24	11.7	113	3.45	1.31	>125
R-200-3	3.42	22	13.2	114	1.93	1.88	>140
R-400-1	3.43	42	11.2	71	2.55	2.30	
R-400-2	3.99	40	13.6	79	4.31	1.85	>105
R-400-3	4.62	30	9.6	155	4.81	1.38	>135
I-100-3	0.36	16	3.2	70	4.95	0.65	105
I-200-1	2.95	65	7.1	79	3.51	1.69	>135
I-200-2	0.79	19	3.8	121	4.32	0.82	> 95
I-200-3	0.36	15	2.5	88	4.07	1.17	105
I-400-1	3.36	41	7.0	118	2.69	1.76	>135
I-400-2	1.36	28	5.0	94	4.68	1.01	105
I-400-3	1.21	29	5.1	80	3.89	1.09	85

(cont'd)

Appendix 5. (cont'd) Physical parameters for survey units which contained adult coho, French Creek, 1986.

Transect	Discharge ($m^3 \cdot s^{-1}$)	Mean Depth (cm)	Mean Width (m)	Mean Current ($cm \cdot s^{-1}$)	Substrate Coarse -ness	Substrate Hetero -geneity	Secchi Depth (cm)
08-11 Dec:							
S-100-1	0.70	23	5.8	52	2.67	1.74	> 95
S-100-2	1.17	28	7.2	58	2.38	1.65	
S-200-2	1.50	24	9.7	76	1.75	1.63	>125
S-200-3	0.23	10	3.4	69	4.25	0.83	> 85
S-400-1	0.65	18	5.2	62	3.86	0.95	> 95
S-400-2	1.12	14	7.8	97	3.81	1.47	
R-400-1	1.14	32	10.8	34	2.55	2.30	
R-400-2	2.16	33	12.7	62	4.31	1.85	> 90
R-400-3	1.87	23	8.9	88	4.81	1.38	>135
I-100-1	1.95	29	8.2	69	4.02	0.99	>110
I-200-1	0.95	51	6.9	45	3.51	1.69	
I-400-1	1.11	29	6.4	62	2.69	1.76	125
I-400-2	0.29	16	3.8	44	4.68	1.01	95
I-400-3	0.35	17	5.1	39	3.89	1.09	75
15-17 Dec:							
S-100-2	1.81	32	7.7	68	2.38	1.65	
S-200-2	3.45	35	11.0	91	1.75	1.63	
S-400-1	1.53	25	5.8	103	3.86	0.95	>105
R-400-1	7.35	57	11.2	111	2.55	2.30	
I-400-1	2.97	41	7.0	103	2.69	1.76	>105
I-400-2	1.11	28	4.6	89	4.68	1.01	>100

Appendix 5. (cont'd) Substrate characteristics on survey transects in French Creek: frequency of occurrence by substrate category.

Survey Type	Unit Size	Rep	Substrate Categories: Large Boulders	Small Boulders	Large Cobble	Small Cobble	Large Gravel	Small Gravel	Sand	Mud	Bed-Rock
S	100	1		1	2	11	7	8	8		26
		2		2		3	6	10	3	1	22
		3				3	11	3	1		
	200	1				21	38	16	8	6	8
		2		6	2	3	1	11	3	1	88
		3				17	18	4		1	
	400	1			1	37	58	42	9	1	
		2		6	7	65	68	22	24	3	20
		3			1	4	17	22	13	1	
R	100	1				8	6		2		
		2				8	15	16	3	1	
		3		4	2	1	5		1		45
	200	1				21	38	16	8	6	8
		2	2	1	9	39	37	30	8	3	
		3			1	29	43	14	2		
	400	1	5	21	10	9	6	11	18		117
		2	1	24	39	32	38	30	14	5	17
		3		15	85	70	48	17	28		
I	100	1				17	31	3	2	3	
		2				2	5	11	1	5	3
		3			4	12	5				
	200	1			6	33	21	7	9	4	19
		2			1	25	18	8	1		
		3			2	18	15	4	6	1	
	400	1	1	3	6	18	32	15	20	8	58
		2		4	11	63	27	6	6		
		3			4	27	41	18	11	2	

Substrate Class	Class Limits (mm)	Class Score
Large Boulders	1024-2048	8
Small Boulders	256-1024	7
Large Cobble	128-256	6
Small Cobble	64-128	5
Large Gravel	32-64	4
Small Gravel	8-32	3
Sand	0.5-2	2
Mud	<0.06	1
Bedrock		1

Appendix 6. Coefficients of principal components based on the correlation matrix of physical variables, and regression coefficients for the prediction of the actual density of coho from the observed density.

(a) Set of electrofishing survey units

Correlation matrix:

	Observed	Discharge	Depth	Current	Width	Coarse
Observed	1.000					
Discharge	-0.016	1.000				
Depth	-0.079	0.631	1.000			
Current	-0.061	0.683	0.185	1.000		
Width	0.138	0.670	0.715	-0.015	1.000	
Coarse	-0.492	-0.504	-0.523	-0.092	-0.656	1.000
Hetero	0.244	0.470	0.690	0.079	0.588	-0.912
Visibil	-0.498	0.638	0.449	0.683	0.194	-0.150
Actual	0.942	-0.157	-0.187	-0.065	-0.011	-0.366

	Hetero	Visibil	Actual
Observed			
Discharge			
Depth			
Current			
Width			
Coarse			
Hetero	1.000		
Visibil	0.283	1.000	
Actual	0.140	-0.434	1.000

Principal Components:

	PC1	PC2	PC3	PC4	PC5
Observed	0.1140	-0.5427	0.5713	0.2725	0.1824
Depth	0.4646	0.1383	-0.3063	0.2423	0.7312
Current	0.1436	0.4787	0.6582	0.2866	0.0698
Width	0.4468	-0.0988	-0.3156	0.6101	-0.4983
Coarse	-0.4876	0.2442	-0.1967	0.2902	0.3206
Hetero	0.5033	-0.1145	0.0113	-0.5510	0.1341
Visibil	0.2447	0.6121	0.0906	-0.1576	-0.2413
Cum. Variance	46.54	74.16	88.32	94.68	98.40

Regression on Principal Components:

Source	DF	SS	MS	F	P
Regression	2	43.495	21.748	16.707	0.001
Error	8	10.414	1.302		
Total	10	53.909			

(R^2=0.806)

Variable	Partial	Coefficient	Std. Error	Signif.
Constant		1.9091	0.3440	0.001
PC2	-0.8379	-1.1266	0.2595	0.003
PC3	0.8034	1.3828	0.3623	0.005

Appendix 7. Coefficients of principal components based on the correlation matrix of physical variables, and regression coefficients for the prediction of the observed density from physical parameters

(a) Set of 57 visual count survey units with fish

Correlation matrix:

	Observed	Discharge	Depth	Current	Width	Coarse
Observed	1.000					
Discharge	-0.101	1.000				
Depth	0.035	0.784	1.000			
Current	-0.338	0.512	0.133	1.000		
Width	0.101	0.777	0.543	0.222	1.000	
Coarse	-0.093	-0.404	-0.475	0.018	-0.412	1.000
Hetero	0.161	0.635	0.735	-0.090	0.736	-0.658
Visibil	-0.198	0.140	0.098	0.291	0.204	0.136

	Hetero	Visibil
Observed		
Discharge		
Depth		
Current		
Width		
Coarse		
Hetero	1.000	
Visibil	0.069	1.000

Principal Components:

	PC1	PC2	PC3	PC4	PC5
Depth	0.4960	0.0214	-0.0167	0.2866	0.7572
Current	0.0775	0.6525	-0.7142	-0.0276	0.0240
Width	0.4913	0.1783	0.0451	0.3904	-0.6402
Coarse	-0.4357	0.2867	0.2656	0.7715	0.0876
Hetero	0.5567	-0.1416	0.1906	0.0683	-0.0554
Visibil	0.0829	0.6631	0.6170	-0.4060	0.0744
Cum. Variance	46.95	70.10	82.68	90.75	98.19

Regression on Principal Components:

Source	DF	SS	MS	F	P
Regression	1	11.428	11.428	6.483	0.014
Error	55	96.956	1.763		
Total	56	108.38			
(R^2=0.105)					

Variable	Partial	Coefficient	Std. Error	Signif.
Constant		1.2193	0.1759	0.000
PC2	-0.3247	-0.3833	0.1506	0.014

Appendix 8. Mortality schedule for adult coho in the Little Qualicum spawning channel, 1986 (data courtesy of M. Labelle, U.B.C.).

Date	No. Entering	No. Dying	No. Alive	Live Fish-days	Instantaneous Mortality Rate
14 Oct	12		12	12	
15			12	12	
16			12	12	
17			12	12	
18			12	12	
19	3		15	15	
20	4	2	17	17	0.143
21	2		19	19	
22			19	19	
23	1		20	20	
24			20	20	
25			20	20	
26	7		27	27	
27	20		47	47	
28	6	1	52	52	0.022
29	2		54	54	
30	10		64	64	
31	61		125	125	
01 Nov	32		157	157	
02	6	1	162	162	0.006
03	4		166	166	
04	4	14	156	156	0.088
05	4	2	158	158	0.013
06	5		163	163	
07	2	18	147	147	0.117
08	1	2	146	146	0.014
09		9	137	137	0.064
10		6	131	131	0.045
11	2	12	121	121	0.096
12	2	5	118	118	0.042
13	8	21	105	105	0.196
14	68	13	160	160	0.132
15	2	11	151	151	0.071
16	1	5	147	147	0.034
17	6	14	139	139	0.100
18	11	23	127	127	0.181
19	16	6	137	137	0.048
20	23	9	151	151	0.068
21	15	11	155	155	0.076
22		4	151	151	0.026
23		16	135	135	0.112
24		18	117	117	0.143
25		9	108	108	0.080
26		6	102	102	0.057
27		6	96	96	0.061

(cont'd)

Appendix 8. (cont'd). Mortality schedule for adult coho in the Little Qualicum spawning channel, 1986 (data courtesy of M. Labelle, U.B.C.).

Date	No. Entering	No. Dying	No. Alive	Live Fish-days	Instantaneous Mortality Rate
28 Nov		14	82	82	0.158
29	52	11	123	123	0.144
30	54	10	167	167	0.085
01 Dec	51	15	203	203	0.094
02		10	193	193	0.051
03		6	187	187	0.032
04		14	173	173	0.078
05		10	163	163	0.060
06		18	145	145	0.117
07		14	131	131	0.102
08		9	122	122	0.071
09		27	95	95	0.250
10			95	95	
11		19	76	76	0.223
12		9	67	67	0.126
13			67	67	
14		26	41	41	0.491
15			41	41	
16		6	35	35	0.158
17			35	35	
18		6	29	29	0.188
19		2	27	27	0.071
20			27	27	
21		28	0	0	>3.332
Total:	497	498		6626	

Average life: 6626/497 = 13.3 days